Author copy. Please cite the published article in The Extractive Industries and Society: Dunia Kabunga, P. and Geenen, S. (2022) Work regimes and technology-driven transformations in DRCongo's artisanal and small-scale gold mines. The Extractive Industries and Society. https://doi.org/10.1016/j.exis.2022.101142

Work regimes and technology-driven transformations in DRCongo's artisanal and small-scale gold mines

Abstract

Over the past two decades growing scarcity and rising costs have pushed artisanal and small-scale gold miners all over the world towards mechanization and technological innovation. Based on qualitative data gathered in the two largest artisanal and small-scale gold mining (ASGM) towns in South Kivu province, Eastern Democratic Republic of Congo (DRC), we analyze what these technological innovations imply for the ASGM work regime, conceptualized as the set of practices used to organize and control workers. We observe transformations in workers' tasks, skills and specializations; a reorganization of working time and space; an evolution in the payment system towards wage labour; a concentration of financial capital; and a strengthening of the position of mining cooperatives. We also stress the embedded and sedimented nature of these transformations.

Keywords: artisanal and small-scale gold mining; technologies; work regimes; labour

1. INTRODUCTION

All over the world, workers can be found with spades, pans, drills, torches or dredges, in search of gold. It is estimated that artisanal and small-scale gold mining (ASGM) contributes up to one-fifth of global gold production (IGF, 2017, p. 3) and employs at least 16 million people worldwide (Seccatore et al., 2014, p. 666). Over the past two decades, researchers have shed light on what drives these ASGM miners. Most allude to push factors such as poverty and lack of alternative income opportunities (Hilson & Garforth, 2013; Siegel & Veiga, 2010; Hilson & Van Bockstael, 2012). While this undoubtedly explains the presence of a massive workforce willing to engage in strenuous physical labour for uncertain earnings, it cannot quite explain the large volumes of gold produced by ASGM, nor the increase in scale resulting from technological innovation and substantial capital investment (Verbrugge & Geenen 2020). This is why Verbrugge and Geenen (2020) have previously argued that the expansion of ASGM should be seen as a response to the systemic challenges facing global gold production, including material scarcity, rising production costs and resistance to large-scale mining. In this sense, ASGM has the advantage to be (largely) informal. That is, it operates outside of formal regulatory frameworks and, as such, avoids a number of costs associated with fiscal, labour and environmental regulation.

Technological innovation in ASGM involves the increasing use of machines for extraction (eg excavators or jackhammers) and processing (eg ball mills), as well as the use of new techniques (eg cyanidation). In the past two decades, these have spread in virtually all ASGM countries in the world (Hilson & Maconachie, 2020; Lanzano & Di Balme, 2021; Lanzano, 2018; Massaro & De Theije, 2018; Verbrugge et al, 2021). ASGM typically operates through complex revenue-sharing arrangements that bring together workers and financiers, but also, in some cases, landowners, customary and/or statutory authorities, and various other rent seekers (Cuvelier et al, 2022; Mensah, 2021). These revenue-sharing arrangements are often based on shares in the production, whereby larger shares accrue to the financiers. Such arrangements are commonly seen as legitimate and create opportunities for social mobility, which is one reason why ASGM is so attractive in a depressed rural environment. At the same time, they allow capital to outsource financial risk to labour. In addition, there are several categories of casual workers - such as those involved in transport, crushing or mineral processing - who are not part of these revenue-sharing arrangements. There is also growing evidence that the current trend towards a more capital-intensive and technologically advanced ASGM goes hand in hand with the emergence of more exploitative labour arrangements (Verbrugge & Besmanos, 2016; Verbrugge & Geenen, 2020) and that ASGM formalization does not benefit poor informal miners, but might be used as a tool for elite capture (Hilson, 2020; Hilson et al., 2017; Hilson et al., 2022; Robles et al., 2022; Siwale & Siwale, 2017; Vogel et al., 2018).

This article contributes to the growing body of literature on socio-technical change and labour in ASGM by presenting the case of the Democratic Republic of Congo (DRC). The DRC is among the countries where ASGM is very important, even if official figures report very low volumes (Geenen & Verbrugge, 2020; Seccatore et al., 2014). It is estimated that at least 12 tons of gold are produced in ASGM each year, mainly in the east of the country. However, in recent years we have observed an accelerated mechanization of production. This can be seen in the widespread use of machines such as ball mills, motor pumps or dredges, and in the introduction of new techniques such as cyanidation. Theoretically, our article makes three contributions : 1) the conceptualization of work regimes as the set of practices used to organize and control mine workers, including the division of tasks and payment, but also spatio-temporal practices and organization into cooperatives; 2) the location of agency in these work regimes, as the ways in which different categories of workers respond differently to transformations; 3) the analysis of technology-driven transformations as embedded (in local socio-political environments) and sedimented (in time).

In what follows, we review the literature on work regimes, labour control and agency. After presenting the methods, we analyze the technology-driven transformations in Congolese ASGM, the ways in which these have impacted on different categories of workers, as well as workers' responses.

2. WORK REGIMES, CONTROL AND AGENCY

Theoretically we frame our contribution within the Global Production Networks (GPN) literature, which has coined the concepts of labour control and agency to understand how labour is embedded in local institutions and power relations, and how it responds to and resists capitalism (Taylor et al., 2013). First, in order to get work done, capital owners must organize, supervise and discipline workers in order to convert labor power (the capacity to work) into actual work (Selwyn, 2013). The set of practices adopted in the workplace to organize and control workers, for instance through training, task distribution and pay, is called the work regime. This concept has been developed in the case of South Africa in particular, where different authors have coined the Apartheid and Post-Apartheid work regime (Phakathi, 2012).

The control of labour is not simply established by force or coercion, but also by the fact that the owners of capital take care of the housing, training, or medical care of the workers. In short, they control not only the conditions of production, but also the conditions of reproduction (Cumbers et al. 2010). These are closely linked to social institutions such as gender, age, ethnicity, migrant status, or in countries like India, caste (Peck, 1996). In her work on the textile industry in India, Mezzadri (2010) highlights a disarticulation between the global scale at which production is organized and the local scale at which work is controlled. Unlike Cumbers et al (2010), she argues that capitalists do not necessarily seek to control labour, at least not directly. For her, capital owners and states - for it is important to recognize the role of the state as well - deliberately transfer control over labour to local institutions and keep production in the informal sphere. For instance, being a migrant, or being a woman, gives you access to less stable and less remunerated work. The socio-political or cultural position of migrants or women maintains them in this vulnerable position (Harriss-White, 2009). Thus, informality and control by social and cultural institutions is very useful for capitalists and states; it frees them from certain costs and obligations.

To be sure, workers are not always, or not merely, passive victims of capitalist forces. Several GPN researchers emphasize workers' agency (see, among others, Carswell & De Neve, 2013; Cumbers et al., 2008; De Neve, 2014; Riisgaard, 2009; Selwyn, 2011, 2013). This agency may derive from their structural power, i.e. the "position of workers in the production process and their ability to disrupt it" (Selwyn, 2011, p. 16), or from associative power through the collective organization of workers. Selwyn's research in the Brazilian grape sector illustrates how workers use their structural and associative power - by exercising collective agency during export window periods that are crucial for Brazilian grape exports to Europe - to successfully extract certain concessions from employers. At the same time, it must be acknowledged that workers' agency is strongly limited by socio-political and cultural structures such as gender. In the textile sector, for example, employers tend to have a preference for female workers because of certain cultural ideas that women have "nimble fingers" or are naturally docile and less inclined to stand up for their rights (Munir et al., 2017). Building on this idea, Phillips (2011, p. 385) argues that companies are not simply looking for a lower cost workforce, but a workforce that has particular characteristics conducive to a specific mode of use.

Workers' skills are a potential source of power too. For instance, Selwyn (2011) explains that workers' structural power may depend on their place in the global production system, but also on their position in the labour market

(structural and marketplace power). Having specific skills that are in high demand can enable a worker to negotiate better working conditions. In his fascinating article on the skills of workers in a furniture factory, Juravich (2017) shows that these skills are often implicit and tactile and reflect collective rather than individual competence. In his case, these skills are revealed during the closure of the factory in the form of the thousands of jigs made by the workers. In the case of the ASGM mines, we also point out how the introduction of machines and new techniques changes the skills that are needed and how this, in turn, affects the power position of particular types of workers.

3. METHODS & CONTEXT

This article is part of a collective effort that aims to understand technological innovations in Congolese ASGM. We selected the two largest ASGM towns in South Kivu province –Kamituga and Misisi – as case studies. A multidisciplinary team (composed of social scientists, biologists and engineers) designed the research questions and the methods, and developed interview guides for different categories of stakeholders and workers. In April and May 2021, they spent two weeks in each site. In Kamituga, 101 people were interviewed, including 26 in focus groups and 75 in individual interviews. In Misisi, they interviewed 127 people, including 28 in focus groups and 99 in individual interviews.

Most team members had previous experience at both sites, which facilitated their access and greatly assisted in building trust. For each interview, the interviewee gave oral consent. After consent, most interviews were also recorded and transcribed *verbatim*. These transcripts were imported and coded using NVivo software. Site observations, informal interviews and participatory mapping during focus groups helped to interpret these data. For the participatory mapping, focus group participants were asked to draw a map of their mine site and indicate the different stages of the production process, as well as the technologies used.

An estimated 121.000 workers are active on around 530 gold mining sites scattered across South Kivu province[1]. Many of these sites are located in areas that have been given in concession to industrial companies, the most important of which was Canada-based Banro Corporation. While other juniors and exploration companies have been active, Banro was the only company that moved into commercial production, until they recently shut down all operations. Legally speaking ASGM is authorized only inside artisanal mining zones, and needs to be carried out by miners organized in officially recognized cooperatives. In practice the number of artisanal mining zones is limited, and almost all gold is produced informally, after which it leaves the country via well established smuggling networks. In 312 of the 530 gold mining sites, armed group presence has been observed according to IPIS data. Concretely, this means in almost all cases that armed actors levy taxes. The volatile security situation, combined with crumbling transport infrastructure, render many mining sites very difficult to access. This also has implications for the spread of (heavy) machinery, which is very costly to transport to the sites.

Kamituga is the largest mining city, situated about 180 kilometres west of Bukavu, the provincial capital. Gold mining began in the 1920s, and industrial mining companies were present until 1996. After that, the permits came in the hands of Banro Corporation, which only did exploration in Kamituga. In the meantime, ASGM, which had started in the 1960s already, had come to dominate. At present there are an estimated 15.000 to 20.000 artisanal miners on a total population of 200,000 (Geenen et al., 2021). According to estimates made in 2013 by Geenen (2014, p. 58), ASGM production in Kamituga ranged from 618 to 840 kilograms per year, or 12% to 17% of the provincial total of 4,800 kilograms (which is again an estimate). Although security in the city centre is established, the situation around the city is still volatile.

Misisi is a mining town located in the south of South Kivu province, in Fizi territory, some 300 kilometres from the city of Bukavu. ASGM mining began in Misisi in 1965. No industrial company has ever worked there. However, there has been interest of exploration companies such as Casa Mining, registered in the British Virgin Islands, which has linked up with Anvil – a Canada based copper producer - through its subsidiary Leda Mining (Mthembu-Salter, 2014). According to official figures from the mining administration, Misisi produced only 13.5 kilogrammes of gold in 2018. The real production is much higher but it is not known, neither is the number of ASGM workers (Mthembu-Salter, 2014). The security situation around Misisi is highly volatile, with both the Congolese army and non-state armed groups levying taxes in several mining sites.

[1] IPIS data available on https://ipisresearch-dashboard.shinyapps.io/open_data_app/.

4. TRANSFORMATIONS IN SOUTH KIVU'S ASGM

Between the 1970s and 2010, ASGM occurred in rivers (panning), underground pits and open pits, in teams of a handful up to more than 100 miners. In alluvial mining, teams were usually quite small and sometimes family-based. Underground pits, mostly not inside a legal artisanal mining zone, were initiated by a pit manager, who had to negotiate with the customary authorities managing the land. The pit manager also financed the operations, but generally relied on prefinancing by gold traders. He also recruited manual as well as some specialist labour such as timber workers. Almost all work was manual. Machinery was limited to water pumps and air compressors in the underground pits, and hydraulic monitors for removing top soil. In underground pits, which employed most workers, the so-called preparatory period could last several months or even years. During this period the pit manager provided food for the workers. Once the gold vein was reached and production started, bags of stones or sand were divided among the pit manager (one third) and workers (one third), with another third to recover expenses made. Specialist workers were generally paid per task, in kind. Every individual worker could then process his material in a fenced-off space called *loutra*, where panners and manual grinders (often female workers called *twangaises*) were involved. Mercury amalgamation was applied at the end of this process, mostly inside houses in the popular neighbourhoods. This system of revenue sharing was appreciated by many miners, who felt it increased their control over their own production. On the other hand, pit managers as well as individual miners were very dependent on financiers, most of the time gold traders. These traders in turn depended on the miners for a continuous gold supply, and sometimes incurred very significant losses if underground mining projects did not succeed (Geenen, 2015).

In the past decade, the wide diffusion of machinery and new techniques has produced unmistakable changes in South Kivu's ASGM. In this article we study what these changes imply for the work regime. Our use of the term "transformations" implies socio-technical change, but also spatial changes, change in work rhythms, changing governance and power. The idea is not that one system (as the one described in the previous paragraph) is fully erased and replaced by a new system. On the contrary, every transformation that unfolds, holds elements of the previous one, like sediments layered in the soil[2]. As Pijpers (2020) puts it in his chapter on Ghana: "[…] although certain actors and activities may disappear with the arrival of new ones, the traces of these previous activities and actors are not erased, but built upon". This also implies that the changes do not go in only one direction, involve all actors to the same extent, or are equally profound in all domains. Here we support the analysis of Lanzano (2018) who states that technological transformations "do not constitute an irreversible trajectory", and Massaro and De Theije (2018), who write that Brazilian ASGM has witnessed "big improvements" (mechanized exploration drill and cyanidation), but also "small novelties [that] made the extraction process smoother and more efficient and did not require too much time to be accepted by the miners". Our analysis below bears witness to the intrinsic multiplicity within these transformations, as well as to their sedimented and embedded nature.

In this section, we first explain how these technology-driven transformations in South Kivu are part of the structural evolutions of the "global gold production system" (Verbrugge & Geenen, 2020) (section 4.1). Next, we describe the emergence of new actors and tasks, which require new skills (section 4.2). In sections 4.3, 4.4, 4.5 and 4.6 we analyze respectively the transformations in the organization of work, in remuneration systems, in the financing of activities, and in the organization into cooperatives.

4.1. New costs, new opportunities

When it comes to the mechanization of ASGM, the DRC is a relatively late adopter. In countries such as the Philippines (Verbrugge, 2014), Indonesia (Libassi, 2020; Verbrugge et al, 2021), Peru (Cortés-McPherson, 2019), Colombia (Robles Mengoa & Uran, 2020), Ghana (Crawford & Botchwey, 2016), Guinea (Dessertine, 2016) or Burkina Faso (Lanzano, 2020), the use of large excavators, mechanized ball mills, metal detectors and cyanide was already widespread more than a decade ago. In South Kivu, they have been introduced around 2010 and have become widespread only in the past five years. This delayed adoption is the result of a combination of factors : the insecurity that has persisted even after the official end of the Congo wars in 2003; the enclave nature of most ASGM mines in the province; and the generalized lack of access to financial capital. That being said, the

[2] We started thinking about this notion when co-authoring a paper with Judith Verweijen and Anuarite Bashizi on sedimented subjectivities (forthcoming). Inspired by Doreen Massey's work, Judith Verweijen came up with the idea of sedimentation to analyze the historical layering of subject formation.

conditions for technological spillovers from large-scale industrial mining to ASGM – a common channel through which technological innovations are introduced in ASGM (Pijpers, 2020; Verbrugge & Geenen, 2020) - are omnipresent. When industrial production dwindled in the 1980s and 1990s, infrastructure was abandoned and plundered. Yet local engineers continue to work with the rubble of colonial technologies and play an important role in the current technological innovations, as highlighted by Marijsse and Munga in this issue.

Table 1 gives an overview of the machines and technologies we identified in Kamituga and Misisi as well as their origin and spread. As Verbrugge and Geenen (2020) have shown, technological innovations are responding to two major challenges facing the global gold production system. On the one hand, the material is becoming increasingly scarce, which is a logical consequence of its non-renewable nature, and the grades of gold in the extracted material become lower. Technologies such as ball mills and cyanide plants are making material that was once unprofitable because of low gold content finally profitable. One respondent in Kamituga said :

> "The ball mills have changed everything. Some pits here were producing very low-grade stones. The same is true for the sand that is reputed to contain low-grade gold. In the past, this sand was just left there. People took it to build their houses. But today it is of great value" (I.TR-202104-pd14).

On the other hand, extraction is becoming more and more expensive, as the most accessible and near-surface deposits are already exhausted, so ASGM miners need to dig deeper, where they face various constraints related to lack of oxygen, mounting groundwater, or stability. ASGM miners in Kamituga and Misisi face similar challenges. Some pits already reach further than 100 metres underground (while according to the Congolese Mining Code the maximum depth for ASGM is 30 metres). Here, miners need air compressors and water pumps.

When looking at the spread of the technologies in table 1, it is clear that the pace and the extent differ. The most widespread technologies are those that require relatively limited investment and can easily be transported. In the specific context of Eastern DRC, one has to take into account the almost inexistence of a road infrastructure, which requires some large machines to be transported in smaller components, on motorbikes or on human shoulders. A second factor is the volatile security context, which renders some sites even less accessible. This reminds us that technological innovations do not unfold unhindered by local political conditions.

Table 1 : Technologies and their impacts on the categories of workers

Machines and technologies	Origin and spread	Emerging workers' categories	Diminishing workers' categories	Description
Metal detectors (*testeurs*)	From Tanzania, Burundi and Uganda Spread: low. A few sites in Misisi	Prospectors with metal detectors	Prospectors (*métaneurs)*	*Métaneurs* interpret geological signs underground to guide the team. Their skills are based on experience and intuition. The new prospectors use *testeurs* (metal detectors).
Excavators	From Tanzania, Burundi and Uganda Spread: low. A few sites in Misisi	Excavator operators	Shovellers (*peleteurs*)	*Peleteurs* use shovels to evacuate stones and sand. Operators operate large excavators (especially in Misisi).
Mercury amalgamation (*cyanage*)[3]	From industrial companies (1980s) Spread: high. All sites	Mercury workers (*cyaneurs)*	*Loutra* owners	Specialized workers coming from a specific industrial mining area in South Kivu where they mastered the technique of using mercury to capture very fine gold particles. They increasingly process the material instead of the *loutriers.*
Cyanidation plants &	From industrial companies (2010s)	Cyanidation workers	Waste processors	Tailings are processed using cyanidation in cyanidation plants. The gold is melted into ingots in melting

[3] The use of the term *cyanage*, which seems to suggest a relation with cyanidation, is surprising and has not been properly explained during field research.

melting furnaces	Spread: medium. 1 in Kamituga, 3 in Misisi		(*mamans bizalu)*	furnaces. Previously this sand was bought by waste processors or *mamans bizalu*.
Tractors	From Tanzania, Burundi Spread: low. A few sites in Misisi	Tractor operators	Manual transporters (*mamans hilux)*	Mechanized tractors have replaced the human transporters (often female called *maman hilux*) (especially in Misisi)
Bicycles	From Tanzania, Burundi and Uganda Spread: low. A few sites in Misisi	Bicycle transporters (*kasomba)*	Manual transporters (*maman hilux*)	Manual transporters have been replaced by machines, given the large volumes of sand that are being processed. Some *kasomba* are now using bicycles to transport in Misisi.
Jackhammers (*marteaux-piqueurs*)	From Tanzania, Burundi and Uganda Spread: medium. Many sites in Misisi, a few in Kamituga	Jackhammer operators *(mutobolistes)*	Drillers *(foreurs)*	Mechanized jackhammers are replacing manual drillers (especially in Misisi).
Motor pumps (*motopompes)*	From China, passing Tanzania and Uganda Spread: high. All sites	Machine operators (*machiniste*)		Machine operators operate and maintain the motor pumps and compressors that have become very numerous in both sites.
Compressors (*compresseurs*)	From China, Tanzania, Burundi and Uganda Spread: high. All sites			
Explosives (*kapata*)	From Tanzania, Burundi and Lubumbashi Spread: high. All sites	Operator of explosives (*bout de feu)*	Drillers *(foreurs)*	Explosives were used in industrial mining, but find their way more and more to ASGM. The *bout de feu* is a specialized worker who places the explosives. Explosives partially replace the manual removal of rocks by the drillers.
Dredges or robot dredges	From China, Tanzania and Uganda Spread: medium. Kimbi river in Misisi, other rivers in South Kivu	Divers		Divers dive underwater while breathing through tubes, and use suction pipes to suck soil from the riverbed.
		Machine operators (*machinistes*)		Robot dredges are fully mechanized, while on normal dredges a machine operators collaborates with a diver.
Ball mills *(concasseurs*)	From Tanzania and Uganda. Some parts (*gorodi*) from Lubumbashi. Some parts are manufactured locally. Spread: high. All sites	Owner (*patron/ PDG*)	Owner (*patron/ PDG*)	The *patron* or *PDG* exists since a long time, but he previously owned a (or more) mining pit. Now the owner of the ball mills is also called *patron* or *PDG.* In addition he may own mining pit(s) or domains.
		Machine operator (*machiniste)*		Machine operators operate and maintain the ball mills that have become very numerous in both sites.
		Welders (*soudeurs*)		Welders are in charge of technical maintenance of the machines.
		Dean (*doyen*)		Deans supervise the transport of sand and stones from and to the ball mill.

		Managers		Financial managers of the ball mills and the domains.
		Crushers (*bongueteurs*)		*Bongueteurs* use hammers to reduce the size of the stones before they are brought to the ball mill.
		Sand and stone buyers *(loteristes)*		They used to buy small quantities of concentrates. But since the introduction of the ball mills they started buying larger volumes of sand and stones directly from *foreurs, peleteurs or PDGs*, particularly in Misisi in a place that is called Kadutu market.
		Stone pickers *(kalokota* or *mamans tora*		Female workers hand picking stones around the pits.
		Water carriers (*kashota)*		Female workers supplying water to cool the ball mills down (in Misisi).
Domain *(Domaine* is the name used in Kamituga, in Misisi *tank* is also used; in this article we use domain)	From Tanzania. Spread: high. All sites	Panners (*kasukula*)		*Kasukula* use a pan and water to pan gold in the domain.
		Sand and stone dryers *(kaanika)*		*Kaanika* dry humid stones or sands as those cannot be easily processed in the ball mills. When the material is dried the owner comes back to collect it and pays the kaanika.
		Gatherers *(bindistes)*		*Bindistes* gather leftovers or burn the bags that have been used to transport sand and stones in order to find gold.
			Panners *(basongueurs)*	*Basongueurs* used to pan for gold in rivers, but the spaces where they worked have been taken over by domains (in Misisi).
		Tailings prospectors *(malolistes)*		Search for tailings and dump sites from where the sand can be profitably processed using the new technologies.

Source : Authors' compilation

4.2. New workers, new skills

Table 1 also relates the spread of the technologies to the categories of workers that have been negatively impacted by them, as well as emerging categories of workers. Three main observations can be made from this table: 1) a trend towards greater specialization, 2) new categories of workers emerging, including new albeit limited opportunities for women, and 3) old categories disappearing or becoming less important.

First, we witness a trend towards greater professional specialization. Some categories of workers master specific technologies that have come to be in high demand. This is the case for prospectors who use metal detectors for exploration, or jackhammer operators. As table 1 shows these machines were imported from Tanzania, Burundi and Uganda. The foreigners who introduced them, transferred their skills to local workers who already had some technical know-how. Sometimes pit managers specifically hired foreign specialist to train their workers. These specialist workers are commonly paid per task, either in a share in the production or – increasingly so - in cash. They are now among the higher remunerated workers.

The *boiseurs* or timber workers already played a very important role before the current transformations: they make the wooden constructions to shore up the underground tunnels. This is important to prevent cave-ins, and since the inside of the tunnels is very humid, the wood needs to be regularly replaced. Now that jackhammers allow for the evacuation of larger volumes of sand, this risks affecting the stability of the tunnels. The technical expertise of the timber workers becomes even more important. Several timber workers we encountered had been doing this job since many years. Some had been working for the industrial mining company that was operating Kamituga's underground mines between 1976 and 1996. This illustrates a second important mechanism of skills transfer: the industrial companies have trained many workers, and they have in turn transferred their skills to their colleagues or children. It stresses the importance of implicit and collective skills transfer as highlighted by Juravich (2017).

Second, mechanization requires new tasks, giving rise to new categories of workers. The ball mills for instance cannot crush stones that are large in size. This is why some stones that come from the underground pits first need to be manually reduced in size. This job is done by the crushers or *bongueteurs.* Unlike the manual grinders, the *bongueteurs* do not grind the stones into a fine powder, but merely reduce the size. They work close to the ball mills, but usually work alone. Also, the humid stones from the pits and sands that come out of the water basins cannot be crushed immediately. They are first dried by another category of workers called the *kaanika,* whom are paid per task by the owner of the stones or sand. *Kaanika* are more active in Misisi than Kamituga according to our observations.

We specifically see the emergence of new categories of workers who are taking advantage of the fact that the new machines increase the volumes that are processed. The jackhammer makes it possible to evacuate a far greater quantity of stones and sand than before. However, these larger quantities also contain materials with poorer grades. Some sand and stone buyers or *loteristes* in Misisi buy these materials to process, while their traditional occupation consisted in buying concentrates only. The presence of ball mills makes this a less risky and potentially profitable business. In transport, the larger volumes of processed material have pushed manual transporters out of work. In Misisi, some of them (*kasomba*) now transport the bags on bicycles.

There is also a proliferation of actors involved in processing tailings, sometimes called 'leftovers' or 'waste'. The production process has become much longer and, it seems, practically infinite, because the material that is left by one category of actors almost always presents an opportunity for another category, who hope to find some gold in it. But it is clear that the further we go in this process, the more the profits fall and become uncertain. Female stone pickers, for instance, gather around the pits to search for mineralized stones (called *majiwe*). They benefit from the ball mills as these allow them to process larger volumes at lower cost. One ball mill operator in Kamituga says:

> "It's mainly all the women you see today picking up stones here and there and bringing them here so that we can grind them for them. This is a category that has emerged and is now found in all the sites where there are ball mills" (I.TR-202104-pd11).

Others recover the leftovers that can be found around the ball mill, or even scrape the inside of the ball mills. In Misisi they are called *bindistes*, from the Kibembe word *bindi* meaning waste. One of them expresses very succinctly the idea of a production process *ad infinitum*:

> "I think the ball mills encourage people a lot to mine even the waste (*bindi*). There is dust to be found in the ball mills. It never ends. People believe that there will always be something even in the waste" (F.TR-202104-pd-1).

Some gatherers have even taken their creativity a step further, burning the bags in which stones and sand have been transported. After burning, they obtain a blackish material. According to some gatherers it takes at least 40 bags to fill a spade with the blackish material, in which you can find a minuscule quantity of gold, if you are lucky. Apart from *bindi*, there is another category of waste in Misisi called *malolo*. *Malolo* are collected in places where stones and sand were once thrown away because they were not profitable. Such places are only known to certain people, mostly (former) ASGM miners who are familiar with the gold mines exploited in the past and who know the local geography and topography. The *malolistes* bring these *malolo* to the ball mills.

Mercury workers use special techniques for mercury amalgamation (see Nkuba et al in this issue). One group of mercury workers originates from the Twangiza area in South Kivu, where they learned their skills from industrial miners. At present, their techniques are in high demand both in Misisi and in Kamituga because they can handle large volumes of waste sand.

These transformations create new opportunities for women, even if they still face many structural constraints. Apart from stone picking, many women work as *kashota* (supplying water to the ball mills); others are *kaanika* (sand and stone dryers) or *bindistes* (gatherers). But, these activities are generally not very profitable. Nevertheless, there are also some women involved in more profitable activities, such as those who own ball mills and domains in both Misisi and Kamituga.

Third, some old categories are disappearing or becoming less prevalent. The *twangueurs* (or female *twangaises)* were manual stone grinders. They are currently threatened by the ball mills, which have absorbed most of their work – although female grinders still occasionally crush small volumes of stones for certain clients. So they have not disappeared, but their services are only solicited for very specific materials or clients. Manual shovelers are being outcompeted by excavators in some open pit mines. Manual drillers are being outcompeted by mechanical jackhammers.

In Misisi, the category of the panners is disappearing because their spaces are taken over by domains. Domains occupy relatively large surface areas as they need to store tailings. They also need a lot of water for washing the material, so they tend to occupy spaces near rivers, or divert water streams towards the domain. This affects the panners who used to work in the rivers. As we will explain later, domain owners – who at the same time often own one or more ball mills - have become one of the more powerful actors in local gold production. An inhabitant of Misisi explains it in these terms:

> "The need for space for domains has put enormous pressure on space occupied by the *basongueurs* or panners. Their work spaces have been taken over by the domains and sand storage areas. On the other hand, these waste sands constitute raw material for the processing units. The *basongueurs* cannot compete with these processing units. Consequently, this category of workers has been weakened here. We could have more than 400 *basongueurs* working along the Misisi River. There are only 75 left that we have identified recently" (I.TR-202105-pd-33).

The processing units in Misisi host a variety of activities, the main one being the reprocessing of tailings. This involves many chemicals such as cyanide, sulphuric acid, nitric acid, borax, lime and carbon, and smelting furnaces for making gold ingots. In Kamituga, a first processing unit using cyanidation had just been opened at the time of our research.

In conclusion, this section has demonstrated that the technological innovations have altered the types of work and the types of skills that are valued in the ASGM mines. A first observation was that mechanization leads to more specialization, something that has also been described in Brazil (Massaro & De Theije, 2018). A second observation concerned the emergence of new workers' categories. Most of the existing literature has focused on this, more specifically on the processing of 'leftovers' and 'waste', and the use of cyanidation. For instance, Jaramillo (2020) argues that "analyzing people's engagement with leftovers […] offers an understanding of resilience and survival in the margins of capitalist cycles of violence". Similarly to our observations in South Kivu, Pijpers et al (2021) have recorded that "there is no waste in gold mining". Yet this gives also rise to new tensions, more particularly conflicts over ownership, as documented by Lanzano and Di Balme (2021). In Kamituga and Misisi, the (new) economic power holders acquire not only ball mills, but also domains where waste is collected. Their economic value is clear, and hence their potential for conflict – although this is not something we have been able to document in this article.

Importantly, these transformations affect different categories of workers in different ways. The observation of the heterogeneity in the ASGM workforce is not new. Ferring et al (2016) have done an excellent job in highlighting the heterogeneity of socio-technical practices in Ghana's ASGM by way of a "one-day catalog", and Libassi (2020) has done the same for small-scale gold mining in Indonesia. But the observation of these changes over time is less common. At the same time our analysis unveils the multiplicity within these transformations. This also comes with some limitations. For instance, our data do not allow us to detail the costs and benefits for each category, and thus come to neat conclusions about the 'winners' and the 'losers' in the process. In this

article on Indonesia, for instance, Libassi (2020) explains that “wealthier miners have benefited from the increased efficiencies” through cyanidation, and that “poorer participants are stuck using mercury and find themselves increasingly dependent on mining bosses”. The sections on capital concentration and cooperatives will allow to more clearly identify some ‘winners’ at the level of the capitalist class.

4.3. New work rhythms, new spaces

In this section we document changes in working hours and the tendency for processing activities to be concentrated in specific places. In terms of work hours, some categories of workers have seen their hours decrease or increase. Inside the pits, drilling and draining activities are now done in a more efficient way. Night work is increasingly being reduced as machines are used to drain. There is no more need for a race to the clock forcing underground miners to work through the night. This also influences the rotation within the teams. One miner explained:

> "Not many people work overnight to drain the water in the pit. With a proper machine,
> you can now use a handful of people where you used to rely on a dozen people working manually. It is a change in the organization of work and the rotation of teams" (I.TR-202105-pd-16).

There are also changes in the spatial organization of the workplace, with the installation of ball mills being a major game changer. In Kamituga, the concession holder Banro initially tolerated the ball mills, but restrained them to only one site, Calvaire (Radley & Geenen, 2021). But since Banro’s departure, the ball mills have rapidly spread over all mining sites in and around the city. In turn, this has led to the proliferation of spaces that are called domain. In such a space, one commonly finds a water pool and an area used as a depository for the waste. As mentioned above domains can cover relatively large surface areas and tend to locate near rivers or water streams. Ball mills and domains are also set up as close as possible to the underground pits, in order to reduce transportation costs. As a consequence, activities tend to be located closer together at all stages of production.

In Kamituga, many processing sites, called *loutra,* were previously located in between the wooden houses in popular neighbourhoods. They hosted the female manual grinders*,* as well as water basins where the grinded stones were panned. Now that the processing activities have shifted, many *loutras* have closed. Also service activities such as small shops, bars or restaurants, are now being drawn closer to the sites where the machines are located. People are building new houses there, extending the original neighbourhoods and approaching themselves to the continuous noise from the ball mills, the heavy metals polluting the water and the dusty air.

We conducted several participatory mapping exercises with mine workers, which illustrate the spatial concentration. Here we provide two examples, showing among others the underground pits (*puits souterrains* on figure 1 and 2), ball mills (*machine* on figure 1, *concasseurs* on figure 2), domains (circles on figure 1 and 2), and offices of the cooperatives (*buro* on figure 2).

Figure 2 : Participatory mapping of Calvaire site in Kamituga

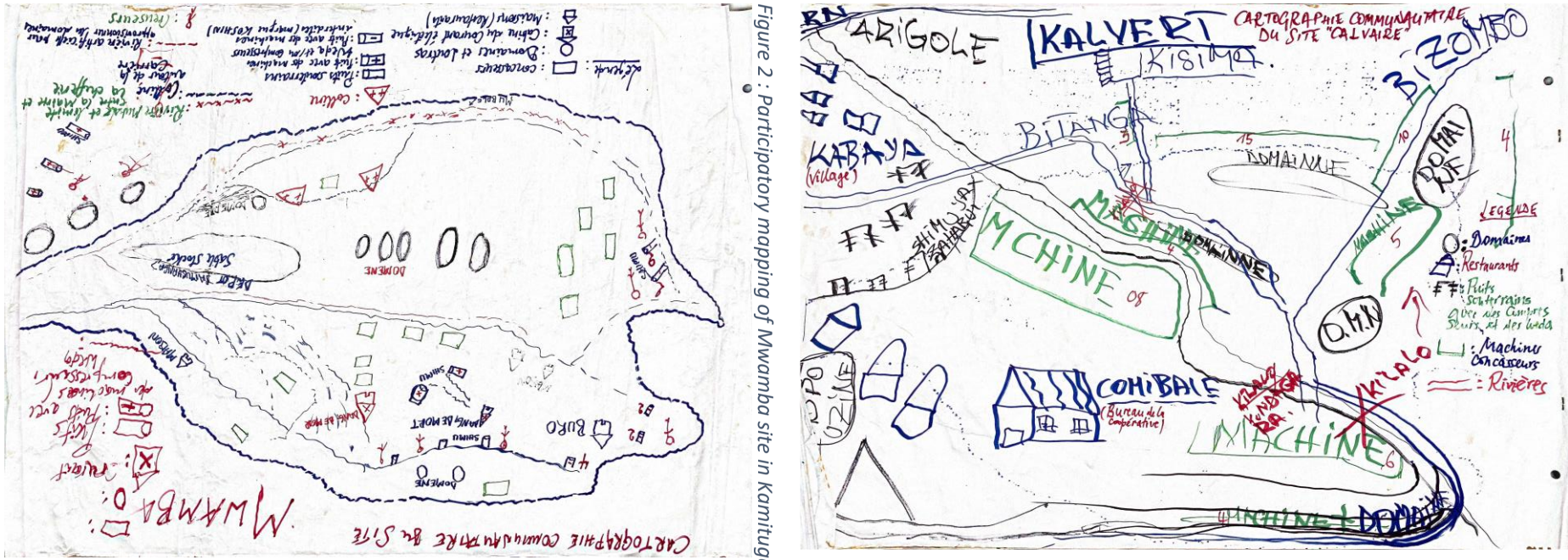

Figure 2 : Participatory mapping of Mwamba site in Kamituga

Several people confirmed that the machines had an impact on the urbanization of the city of Kamituga:

> "When we moved here, there were no houses. You know that the new neighbourhoods here such as Vatican and Kabaya did not exist in the past years. There is Mr. Mutete who had first settled in the Vatican district. He is now the chief of the district. But, at the time, it was like madness for someone to settle in a remote place but he already knew that the machines installed here would attract people a little later" (F.TR-202104-pd-2).

Urbanization is also noticeable around the Misisi sites:

> "Misisi was a forest. From the moment the ball mills were installed, people started to build. The site that hosts the ball mills, for instance, was a few years ago in a place that was really far from the inhabitants. But, as time went on, the inhabitants settled around the machines. The cooperative had decided to relocate the site" (I.TR-202105-pd-5).

Another consequence of the new spatial organization is that the concentration of activities allows for more discretion and control. If the material has to be transported over long distances, it becomes very visible, which may lead to jealousy and even insecurity for the owner. An interviewee in Kamituga says:

> "Everyone in the neighborhood could tell if you produced or not. Today, the whole process is done at the site itself, and people will not notice" (I.TR-202104-pd10).

At the Calvaire site in Kamituga, another worker says:

> "Everything is now concentrated in the mining sites. You mine the products and process them here and then you go home. No one will know whether you have produced or not. All three [ball mills, domains and *loutras*] are often in close proximity" (I.TR-202104-pd14).

In the same sites, mining cooperatives have reinforced their presence. They have offices there and a permanent presence of agents. As we will discuss in section 4.6, their power has grown now that they have better oversight of the different activities in the gold production system.

In brief, we retain that technology introduces new work rhythms and tends to produce a spatial concentration of activities, which has an impact in terms of urbanization and in terms of control over the production. ASGM has been described as an important driver of urbanization in African (Bryceson et al, 2020) and Latin American (Kolen et al, 2018) contexts, but the spatial reorganization inside gold mining sites has received less attention. Yet for Indonesia Libassi (2020) describes that extraction areas and residential area became separated after the government decided to more actively police informal mining sites. This resulted in a new division of labour (for instance more transporters were needed) and more specialization, as well as a broader involvement of the community, including women and children, in the processing activities. Our case also shows that the spatial reorganization impacts on the work regime. Specifically, it simultaneously allows for more control, by centralizing all processing activities in one place, and more secrecy to the outside world, as material moves less over long distances.

4.4. Wage work

The introduction of machines has changed the way production is shared. As we described, workers used to be paid in bags of stones or sand, around a third of total production. Since the introduction of machines, wage labour has become increasingly the norm for many categories of workers. This form of contractual work did not exist previously, as one worker explains:

> "For example, for ball mill workers there are fixed monthly wages. This payment method did not exist before. This is due to the fact that ball mills are technologies that bring in cash. That is why wages are paid" (F.TR-202104-pd-2).

Two forms of wage labour currently exist. Some workers are paid a monthly wage plus a daily food ration in cash. This is the case for the machine operators who operate the ball mills. Typically, these machine operators have little previous work experience. They are generally quite young and learn the technicalities on-the-job. According to our interviews they earn between $25 and $50 per month, and they receive a daily ration of $1.5 to $2.5. Many complain about these derisory wages. When we compare this wage with miners' earnings under the production sharing system, we indeed find this to be very low. On the basis of a survey carried out in 2015 in Kamituga, Geenen et al. (2021) found that PDGs earn on average $191 per week, their right-hands (technical directors and supervisors) $92, experts $52 and shovelers $24.

Other technical workers are paid per task. While previously this was only the case for timber workers and explosive operators, nowadays this system seems to spread to all underground workers, namely drillers and shovelers:

> "There are some changes. Because in the last few years, workers are starting to be paid per hour even in the pits. There are several pits where they start to pay per hour. For example, to execute a specific task, the pit owner agrees with this team to work for him for so many hours. He will pay. Shortly afterwards, if he needs to move on with the same team, he has to agree with them again. And if he wants to change it, he will look for another team. And gradually the operation will be moving forward. The technician who has to drill with the jackhammer is paid per hour. Maybe only the machine operator who manages the part of the engine that stays outside the pit is paid monthly" (I.TR-202105-pd-16).

It is difficult to know how far this trend will lead, but it is likely to affect even the other categories of workers that still apply production sharing. One aspect that has been documented to be very important under the production sharing system, is the feeling of control that workers themselves have over their earnings. Since they were responsible for processing the material they felt a greater sense of freedom, with all the uncertainty and hope that came with it (Geenen, 2018; see also Bryceson & Geenen, 2016; Fisher, 2007). This can explain why even in formalized mines, workers still prefer the production sharing arrangement, as Robles et al (2021) have argued in the case of the Philippines. Also Libassi (2020) argues that wage labour "significantly reduces their autonomy, makes them directly reliant on their bosses, and often involves arduous, repetitive labor." Verbrugge (2020) describes a system of cash sharing, which has replaced ore sharing in the mines in the Philippines where cyanidation was introduced. He writes: "Many respondents noted that cash sharing is very difficult to monitor, as miners have no way of knowing whether the amount they receive represents their fair share". Our study confirms that wages and cash shares lower the feeling of control workers have.

Some elements of the previous production system persist, such as the food rations. These were previously paid in kind, but are now also increasingly replaced by cash payments. This is something the workers we interviewed do appreciate, as it increased their ability to make their own choice.

4.5. Capital concentration

The introduction of new technologies and mechanization requires more capital investment. Previously the investment and operational costs for underground mining operations, which included chisels, shovels, water pumps, fuel, and taxes, were borne by pit managers or by gold traders through prefinancing arrangements (Geenen, 2015, but also Fisher, 2007 for Tanzania). Now we see the emergence of another economically powerful category: the ball mill owners, who often expand their activities into domains too. These ball mill owners need to secure a continuous supply of materials to their mills, so they have an incentive to prefinance. Competition is high as the number of ball mills continues to grow. In Misisi's Miba site alone, for instance, there are around 200 active ball mills. In Kamituga, we counted a total of 232 operational ball mills. In this sense, the financing system works in the same way as the previous one, which involved gold traders only.

> "The current system is that the ball mill owner has to pay all the expenses that the miner would have to bear. You have to pay the taxes, the transporters, the panners. Afterwards, when we find less gold than we expected, the miner loses but the owner as well" (F.TR-202105-pd-14).

The ball mill owners have different backgrounds. Some are key players in local miners' cooperatives, such as board members or managers. Others are former pit managers who accumulated enough to invest in machines. Still others are local businessmen, seeking investment opportunities. One boss in Misisi owns nine ball mills and

told us he plans to install six more in the coming months (I.TE-202105-PD-30). He also owns a cyanidation plant. In Kamituga, a first cyanide processing plant was installed in 2021. It operates under the umbrella of a local cooperative, Kaga Développement, but with funding from a large economic operator based in Bukavu. As such, the increasing financial needs of the mining operations allow some economically powerful people to consolidate their position and control over different stages in the production. As mentioned above, the new technologies generate more stable revenues, allowing for the steady accumulation of more capital. Some of the financial capital needed for the new technologies also hails from foreigners. In Misisi, for example, Tanzanians have created the waste processing units (*unites de traitement*).

Interestingly we also find a form of solidarity financing in place in some of the domains. The owners of the domain prefer not to sell in small quantities. Some waste processors, notably female ones, therefore pool their capital together in order to get access to the tailings (F.TR 202104-pd-3).

We conclude that the investments in machines and new technologies require more financial capital, which is provided by both domestic and foreign actors (see also Radley, 2022). In the cases we have studied, these are mainly Tanzanians. But there is also a growing involvement of Chinese investors and small-scale companies in gold mining in the region, primarily in dredging. This follows a trend of growing Chinese investment that has been documented in other African countries such as Ghana (Crawford & Botchwey, 2016), Zimbabwe (Mkondzongi & Spiegel, 2019) or Cameroon (Weng & Margules, 2022).

The financial capital also seems to concentrate more and more in the hands of a small number of powerful businessmen or “entrepreneurs” (Hilson & Maconachie, 2020). They see the ball mills, domains and cyanidation plants as stable sources of revenue. This is noteworthy, since the ASGM literature has so far mostly looked at cyanidation as a key driver of labour reorganization, as exemplified in Verbrugge et al.’s (2021) article “The cyanide revolution”. Based on their research in the Philippines, Indonesia and Burkina Faso, they conclude that “in all three cases, cyanidation fits in with a broader trend towards vertical integration and consolidation in the value chain, whereby a limited number of actors with access to capital (and in some cases to political power) succeed in capturing most of the value added by cyanidation. Poorer miners and laborers, meanwhile, can only gain access to these benefits by accepting partial losses in the forms of milling fees, transaction costs, or worsening labor terms”. This seems to be confirmed by the current situation in South Kivu, where – even before the “cyanide revolution” has come to full speed - ball mills and domains are driving similar transformations.

4.6. Cooperatives

Miners’ cooperatives and associations have been active in South Kivu’s mining sites since several decades. They defend members’ interests, intervene in disputes, or look after widows and children in case a member dies. Since 2011, artisanal miners in the DRC also have a legal obligation to group in cooperatives. A cooperative can then apply for a permit to mine a specific artisanal mining zone. In the cases under study the mechanization of ASGM has changed the role played by cooperatives. In particular, there has been an increase in the number of cooperatives in the different sites, and a strengthening of their power.

This increased power is first of all visible in their control over the spatial organization of the site. Cooperatives have been assigned specific sites to manage. In the case of Kamituga, this can be qualified as a semi-formal arrangement. Although the cooperatives have been registered with the Ministry of Mines, the entire Kamituga concession is still legally in the hands of Banro Corporation, so no legal artisanal mining zone has been created. Yet Banro has decided to lease the land to cooperatives. Cooperatives do not pay a contribution to Banro, but the agreement stipulates they need to vacate the land again as soon as Banro or its buyer would claim it back. When someone wants to install a ball mill or a domain in this site, the person needs to obtain the permission from the cooperative.

Second, cooperatives manage tax collection in their sites. State services thus depend on them to identify the taxable subjects and to organize the collection. In this sense, a worker says :

> "Sometimes it is the cooperative that collects the taxes according to the number of people subject to the law and the cooperative deposits this with the relevant state services. But there have also been times when there have been arrangements between individual miners and state agents” (I.CO3-202105-PD-24).

The cooperatives also fix the price of certain services, such as crushing by the ball mills :

> "The price we set has been fixed by the cooperative. And it is in collusion with the cooperative that we can decide to increase the price if necessary. We are not like other traders who are free to set the price of their goods" (I.TR-202105-PD-5).

Cooperatives can also suspend underground mining operations for safety reasons, or any other reason such as refusal to pay a tax. According to many interviewees, cooperatives fall short in monitoring safety and security in the sites, as well as in providing technical or material assistance. The cooperatives themselves however insists on this role, although several do acknowledge a lack of resources. A manager of a cooperative states:

> "We try to do the pit inspection together with the pit owner and technicians. Because this is the only appropriate way to get our members to understand the risks. If the pit owner is willing to listen, he will follow up on our recommendations. Otherwise, if he refuses and we are really sure that the danger is imminent, we can forcibly stop the activities in his pit" (I.CO3-202105-PD-24).

Finally, cooperatives have an important role to play in dispute settlement. For example, when there is an accident, the cooperative will intervene to negotiate between the owner of the pit or the machine that produced the accident, and the (family of the) victim.

It must be said that cooperatives are criticized by many workers. Some feel that they are subservient to the state services, defending the interests of the state rather than those of the workers. Workers also pay several contributions to cooperatives, for which they do not always see a return. In theory, cooperatives should provide some technical assistance (as should the state service SAEMAPE or *Service d'Assistance et d'Encadrement du Small Scale Mining*), but in practice this is not always the case. Bashizi and Geenen (2014) and De Haan and Geenen (2016) have already demonstrated the lack of bottom-up initiatives and risks of elite capture in the creation of Congolese mining cooperatives. With mechanization, this logic risks being reinforced. In response, some workers seek to create their own associations – often grouped by occupation - which may allow them to better defend their collective interest. A miner in Kamituga says :

> "We have formed our association of *machinistes* to defend our interests and above all to support us as the cooperative tends to push us aside" (I.TR-202104-PD-11).

Another machine operator confirms their association meets "once a week and members contribute 1000 Congolese francs. This still gives us a lot of capacity to support ourselves in a way that the cooperative rarely does " (I.TR-202104-PD-15). Mercury workers have also formed their own association. For them, protection is much more important as their work is illegal. Someone who used to be a mercury worker says : "It is hard work and carries a lot of risk of getting arrested. But, I believe the mercury workers have been less bothered for a while now because they have an active committee" (I.TR-202105-PD-31). These associations defend very specific interests, and they are closer to their members than some of the cooperatives. However, they are not welcomed by the official cooperatives, who see them as competitors, wrapping this in language about "informality" and "poor organization". Machine operators confessed to us that cooperative leadership takes every opportunity to repress their association, which reinforces the observed tendencies about the undemocratic nature and elite capture tendencies in official mining cooperatives in the DRC and elsewhere (Huggins et al, 2017). Once again, we see that the transformations in the way in which labour is governed by cooperatives are embedded within the socio-political context. More specifically, the government's push towards cooperative organization, and local businessmen and politicians taking advantage of this to take control over these cooperatives and, consequently, over gold production.

5. CONTROL AND AGENCY IN THE WORK REGIME

Our analysis builds on the assumption put forward by Verbrugge and Geenen (2020) that technological innovations and capital investments in ASGM are a systematic response to the problems of material scarcity (increasingly deeper and lower grade gold) and rising production costs. Our case studies have confirmed the trend towards mechanization and intensification of ASGM production that has already been observed in many other countries. While previous studies have focused a lot on cyanidation as the main driver of labour

reorganization (Massaro & De Theije, 2018; Lanzano & Di Balme, 2021; Verbrugge et al, 2021), our cases show that even when cyanidation is not yet very widespread, other technologies prompt similar transformations. Most significantly, ball mills are making it possible to revalorize materials that were previously abandoned because of their low profitability. Moreover, many pits that were abandoned due to the high costs of their exploitation are now being put back into operation thanks to machines such as water pumps and air compressors as discussed by Bikubanya and Radley in this issue.

The introduction of machines and new technologies has changed the work regimes. In this section we conceptualize such changes in terms of control and agency. There are clear indications of a tightened control over the spaces of production, over financial capital, and the payment system. This control is established by the ball mill owners, who increasingly also take control over other production stages such as tailings processing in the domains, and the cooperatives. Workers have responded to this in different ways. Some have shifted occupations; others have specialized; and still others have been pushed out of work. While the cooperatives seem to fall short as sources of associational power, some limited attempts are being made to gather workers in associations – which are in turn repressed by official cooperatives. The diversified impact on different categories of workers makes it difficult to draw unambiguous conclusions concerning 'who wins' and 'who loses' in these transformations.

First, we have documented the emergence of new actors. Some categories of workers are stifled by the competition brought about by machines. Other categories are strengthened, thanks to the fact that machines make their activities easier and faster. Some tasks require new skills. There is a growing trend towards greater specialization, for example in the prospecting stage, in drilling (with the jackhammer), or in mercury amalgamation. It is interesting that for the latter category of workers, for example, this is a technique that dates back to the time of the colonial and post-colonial enterprises, and which had been preserved by a small group of specialists in a particular site. The more technical occupations such as *mutobolists*, who handle the jackhammer, are among the best paid activities today. Whereas in the past, drillers were part of the team that operated a single pit under the supervision of a pit owner, now *mutobolistes* offer their services to several pit owners. Their particular skills make them highly sought after in the market. According to Selwyn (2011), this is an important source of power.

Other big transformations occurred in the strengthening of the cooperative power. On the one hand, cooperatives help to manage and supervise activities in the sites, including technical assistance and safety control, but on the other hand they are also criticized for demanding too many financial contributions. Yet it is clear that associational power (Selwyn, 2011) is a potential source of capital power, especially in this institutional context that is uncertain (at the level of the property rights) and insecure (because of armed conflict). At the level of the organization of work on the site, we have identified some temporal and spatial changes. Thanks to the machines, night work is reduced. Nevertheless, the ball mill operators have to work a lot. As such, the machines tend to produce different effects on the work regime depending on the workers' categories. In terms of spatial organization, there is a concentration of activities around the ball mills and the domains. This facilitates the control by the owners – ball mill owners sometimes also owning the domains.

A significant change is observed in the payment system. Where previously individual workers received a share of the production in kind, which they would process themselves in the *loutra*, there is now a trend towards wage work and cash payments. At the same time, fixed shift work in the pit is moving towards a contractual work system. There are more and more workers who are paid either monthly, or task-based. In addition, there are many new categories of workers, such as stone pickers, bicycle transporters, machine operators, *bindistes*, *kasukula*, and *malolistes*. They emerge in response to some new opportunities created by the new technologies. Yet many of them work with tailings, dust, or even ashes of burnt bags, resulting in very small profits. Finally, mechanization requires more financial capital, creating opportunities for the holders of capital to take up new roles, for instance as ball mill or domain owners, or acquiring a high position in the cooperatives.

In brief, we observe that workers' power is being reduced, as production shares are being replaced by wages and cash payments, manual labour is being replaced by machines, and specialized labour becomes more valued. Yet in response to these transformations, workers maneuver opportunities and constraints by taking up new tasks, developing their skills on the job or pooling their money to buy tailings. The new temporal and spatial arrangements provide some advantage for some workers: they reduce work hours for underground drillers, or make it possible to 'hide' the production from the possibly jealous eyes of the neighbours. On the other hand,

they increase the control of the owners of capital and the miners' cooperatives, which do not always act upon their mission of defending workers' interests. In this whole process of work regime transformation, it is key not to lose sight of how different categories of workers are differently affected. This detailed case study on work regimes in ASGM contributes to the general literature on labour agency and control by providing rich empirical insights into a sector in transformation, with due attention paid to the heterogeneity within the workforce.

6. CONCLUSION

All over the world, ASGM operations seem to move in similar directions: from very small manual mining to medium-sized, even large and mechanized operations. These changes have different paces and intensities, but a trend towards mechanization, scaling up and intensified extraction is discernable. In Eastern DRC such technological changes have intensified in recent years, resulting in transformations in workers' tasks, skills and specializations; a reorganization of working time and space; an evolution in the payment system towards wage labour; a concentration of financial capital; and a strengthening of the position of mining cooperatives. Contributing to a growing body of literature that aims to assess the implications of such technological innovations for labour, this article makes three contributions.

First, we conceptualize work regimes as the set of practices used to organize and control mine workers, including the division of tasks and payment, but also spatio-temporal practices and organization into cooperatives. We conclude that workers' power is being reduced. The new spatial arrangements allow for more control over the workers, and the cash payments reduce the feeling of control that workers have over their own production. Financial capital and, hence, decision making power, becomes more concentrated in the hands of a small number of businessmen and cooperative leaders. At the same time, as a second contribution, we study the ways in which different categories of workers respond to these transformations. While seeing workers' power reduced in many ways, we also identify attempts to collectively organize *from below* or to pool financial resources. We see some higher skilled and specialized workers enjoying better remuneration because of their increased marketplace power. Third, we analyze the technology-driven transformations as embedded and sedimented. Embeddedness refers to the fact that socio-political and security conditions in the surrounding environment affect how the technological innovation will spread. The sedimented nature of transformations refers to the fact that elements of previous working regimes persist in the new ones. As such, the transformations are always ongoing, just like stones are transformed into gold and waste, less gold and more waste, and still less gold and more waste.

Acknowledgements

We would not have been able to carry out this research without the help of numerous people in Kamituga and Misisi, including all interviewees and local authorities. Special thanks to the other members of the team and contributors to this special issue, for a wonderful journey together. We thank CEGEMI and the Catholic University of Bukavu for their continued support, and the VLIR-UOS, FWO, IOB and the University of Antwerp for funding.

Funding

This article has benefited from the support of two different projects. Firstly and most importantly, a project entitled Winners and Losers from Globalization and Market Integration, funded by the Research Foundation Flanders (FWO) and the National Foundation for Scientific Research (FNRS) through its EOS programme (G056718N). A sub-project under the coordination of prof. Sara Geenen focuses on technological change in artisanal and small-scale gold mining. Second, a project on health and environment in artisanal and small-scale gold mining, funded by the Global Minds programme of the Flemish Interuniversity Council (VLIR-UOS) through the University of Antwerp in Belgium and executed in collaboration with the Centre d'Expertise en Gestion Minière (CEGEMI) at the Catholic University of Bukavu (UCB) in the DRC.

Reference list

Bashizi, A. & Geenen, S. (2014). The limits of 'governance from below': the logics of mining cooperatives in Kalimbi, South Kivu. In: Marysse, S. and Omasombo Tshonda, J. (eds.) *Conjonctures Congolaises 2014. Politiques, territoires et ressources naturelles: changements et continuités,* Cahiers Africains, Paris, L'Harmattan, 239-260.

Bryceson, D.F. & Geenen, S., (2016). Artisanal frontier mining of gold in Africa: Labour transformation in Tanzania and the Democratic Republic of Congo. *African Affairs*, 115(459), 296-317.

Bryceson, D.; Bosse Jønsson, J. & Clarke Shand, M., (2020). Mining mobility and settlement during an East African gold boom: seeking fortune and accommodating fate. *Mobilities*, 15(3), 446-463.

Carswell, G. & De Neve, G. (2013). Laboring for global markets: conceptualizing labor agency in global production networks. *Geoforum*, *44*, 62-70.

Cortés-McPherson, D. (2019). Expansion of small-sclae gold mining in Madre de Dios: 'capital interests' and the emergence of a new elite of entrepreneurs in the Peruvian Amazon. *The Extractive Industries and Society, 6*(2), 382-389.

Crawford, G. & Botchwey, G. (2016). Foreign involvement in small-scale mining in Ghana and its impact on resource fairness. In Pichler, M. , Staritz, C. , Küblböck, K., Plank, C. , Raza, W., & Ruiz Peyré, F. (eds.), *Fairness and Justice in Natural Resource Politics* (pp. 181-199). London and New York, Routledge.

Cumbers, A. , Nativel, C. & Routledge, P. (2008). Labour agency and union positionalities in global production networks. *Journal of Economic Geography*, *8*(3), 369-387.

Cuvelier, J., Geenen, S. & Verbrugge, B. (2022) Governance. In: D'Angelo, L. & Pijpers, R. (eds.) *The anthropology of resource extraction.* Routledge.

De Neve, G. (2014). Fordism, flexible specialization and CSR. How Indian garment workers critique neoliberal labor regimes. *Ethnography*, *15*(2), 184-207.

Dessertine, A. (2016). From pickaxes to metal detectors: gold mining mobility and space in Upper Guinea, Guinea Conakry. *The Extractive Industries and Society*, *3*, 435-441.

De Haan, J. & Geenen, S. (2016). Mining cooperatives in Eastern DRC. The interplay between historical power relations and formal institutions. *The Extractive Industries and* Society 3 (3): 823-831.

Ferring, D.; Hausermann, H. & Effah, E. (2016). Site Specific: Heterogeneity of Small-Scale Gold Mining in Ghana. *The Extractive Industries and Society* 3(1): 171-84.

Fisher, E. (2007). Occupying the margins: labour integration and social exclusion in artisanal mining in Tanzania. *Development and Change*, 38(4), 735-760.

Geenen, S. (2015). *African artisanal mining from the inside out. Access, norms and power in Congo's gold sector,* Routledge, Abingdon.

Geenen, S. (2018). Underground dreams. Uncertainty, risk and anticipation in the gold production network. *Geoforum 91*, 30-38.

Geenen, S. ; Stoop, N. & Verpoorten, M. (2021). How much do artisanal miners earn? An inquiry among Congolese gold miners. *Resources Policy, 70,* 101893.

Harriss-White, B. (2009). Globalization, The Financial Crisis and Petty Production in India's Socially Regulated Informal Economy. *Global Labor Journal, 1*(1), 152-177.

Hilson, G. (2020). 'Formalization bubbles': A blueprint for sustainable artisanal and small-scale mining (ASM) in sub-Saharan Africa. *The Extractive Industries and Society*, 7, 1624-1638.

Hilson, G. & Garforth, C. (2012). Agricultural poverty and the expansion of artisanal mining in Sub-Saharan Africa: experiences from Southwest Mali and Southeast Ghana. *Population research and policy review*, *31*(3), 435-464.

Hilson, G. & Van Bockstael, S. (2012). Poverty and livelihood diversification in rural Liberia: exploring the linkages between artisanal diamond mining and smallholder rice production. *Journal of Development Studies*, *48*(3), 413-428.

Hilson, G.; Hilson, A.; Maconachiec, R.; McQuilkena, J.; Goumandakoyea, H. (2017). Artisanal and small-scale mining (ASM) in sub-Saharan Africa: Reconceptualizing formalization and 'illegal' activity. *Geoforum*, 83, 80-90.

Hilson, G. & Maconachie, R. (2020). Entrepreneurship and innovation in Africa's artisanal and small-scale mining sector: Developments and trajectories. *Journal of Rural Studies,* 78, 149-162.

Hilson, G.; Bartels, E. & Hu, Y. (2022). Brick by brick, block by block: Building a sustainable formalization strategy for small-scale gold mining in Ghana. *Environmental Science and Policy*, 135, 207-225.

Huggins, C.; Buss, D. & Rutherford, B. (2017). A 'cartography of concern': Place-making practices and gender in the artisanal mining sector in Africa. *Geoforum,* 83, 142-152.

Jaramillo, P. (2020). Mining Leftovers: Making Futures on the Margins of Capitalism. *Cultural Anthropology* 35(1), 48-73.

Kolen, J.; de Smet, E. & de Theije, M. (2018). "We are all Garimpeiros:" Settlement and Movement in Communities of the Tapajós Small-Scale Gold Mining Reserve. *The Journal of Latin American and Caribbean Anthropology*, 23(1), 169-188.

Lanzano, C. (2018). Gold digging and the politics of time: Changing timescapes of artisanal mining in West Africa. *The Extractive Industries and Society*, 5, 253-259.

Lanzano, C. (2020). Guinea Conakry and Burkina Faso: Innovations at the periphery. In Verbrugge, B., & Geenen, S. (2020), *Global gold production touching ground*. Palgrave, 245-262.

Lanzano, C. & Arnaldi di Balme, L. (2021). Who Owns the Mud? Valuable Leftovers, Sociotechnical Innovation and Changing Relations of Production in Artisanal Gold Mining (Burkina Faso). *Journal of Agrarian Change,* 21(3), 433-58.

Libassi, M. (2020a). Mining Heterogeneity: Diverse Labor Arrangements in an Indonesian Informal Gold Economy. *The Extractive Industries and Society*, 7(3), 1036-45.

Libassi, M. (2020b). Indonesia. Adaptation and differentiation in informal gold mining. In: Verbrugge, B. & Geenen, S. (eds). *Global gold production touching ground. Expansion, informalization, and technological innovation*. Basingstoke: Palgrave.

Massaro, L. & de Theije, M. (2018). Understanding Small-Scale Gold Mining Practices: An Anthropological Study on Technological Innovation in the Vale Do Rio Peixoto (Mato Grosso, Brazil). *Journal of Cleaner Production* 204, 618-35.

Mensah, L. (2021). Legal pluralism in practice: critical reflections on the formalisation of artisanal and small-scale mining (ASM) and customary land tenure in Ghana. *The Extractive Industries and Society*, 8, 100973.

Mezzadri, A. (2010) Globalisation, informalisation and the state in the Indian garment industry. *International Review of Sociology*, 20(3), 491-511.

Mkodzongi, G. & Spiegel, S. (2019). Artisanal Gold Mining and Farming: Livelihood Linkages and Labour Dynamics after Land Reforms in Zimbabwe. *The Journal of Development Studies*, 55(10), 2145-2161.

Munir, K., Ayaz, M., Levy, D. & Willmott, H. (2017). The role of intermediaries in governance of global production networks: Restructuring work relations in Pakistan's apparel industry. *Human Relations*, 1-24.

Mthembu-Salter, G. (2014). *Etude de base: mine d'or artisanale de Mukungwe, au Sud-Kivu, RDC*. Paris: OCDE. Récupéré de https://www.oecd.org/fr/daf/inv/mne/Gold-Baseline-Study-2-FR.pdf.

Peck, J. (1996). *Work-place. The social regulation of labour markets.* New York, London: The Guilford Press.

Phakathi, T.S. (2012). Worker agency in colonial, apartheid and postapartheid gold mining workplace regimes. *Review of African Political Economy*, *39*(132), 279-294.

Phillips, N. (2011). Informality, global production networks and the dynamics of 'adverse incorporation'. *Global Networks,* 11(3), 380-397.

Pijpers, R. (2020). Ghana: a history of expansion and contraction. In: Verbrugge, B. & Geenen, S. (eds). *Global gold production touching ground. Expansion, informalization, and technological innovation*. Basingstoke: Palgrave.

Pijpers, R., van de Camp, E., Fisher, E., Massaro, L., Calvimontes, J., D'Angelo, L. & Lanzano, C., (2021). Mining 'Waste'. *Etnofoor*, 33(2), 13-40.

Radley, B. & Geenen, S. (2021) Struggles over value: corporate–state suppression of locally led mining mechanisation in the Democratic Republic of the Congo. *Review of African Political Economy*, 48(168), 161-177.

Radley, B. (2022). Class Formation and Capital Accumulation in the Countryside: Artisanal and Small-Scale Gold Mining in South Kivu, DR Congo. *Journal of Agrarian Change*, 22(2), 398-414.

Riisgaard, L. (2009). Global Value Chains, Labor Organization and Private Social Standards: Lessons from East African Cut Flower Industries. *World Development, 37*(2), 326-340.

Robles Mengoa, E. & Uran, A. (2020). Colombia: Legal Loopholes behind Illegal Gold Trade. In Verbrugge, B. , & Geenen, S. (2020), *Global gold production touching ground*. Basingstoke: Palgrave.

Robles, M.E.; Verbrugge, B. & Geenen, S. (2022) Does formalization make a difference in artisanal and small-scale gold mining (ASGM)? Insights from the Philippines. *The Extractive Industries and Society*.

Seccatore, J., Veiga, M., Origliasso, C., Marin, T. & De Tomi, G. (2014). An estimation of the artisanal small-scale production of gold in the world. *Science of The Total Environment*, 496, 3-8.

Selwyn, B. (2011). Beyond firm-centrism: re-integrating labor and capitalism into global commodity chain analysis. *Journal of Economic Geography*, 12(1), 205-226.

Selwyn, B. (2013). Social upgrading and labor in global production networks: a critique and alternative conception. *Competition and Change*, *17*(1), 75-90.

Siegel, S. & Veiga, M. M. (2009). Artisanal and small-scale mining as an extralegal economy: De Soto and the redefinition of "formalization". *Resources policy*, *34*(1-2), 51-56.

Siwale, A. & Siwale, T. (2017). Has the promise of formalizing artisanal and small-scale mining (ASM) failed? The case of Zambia. The Extractive Industries and Society, 4, 191-201.

Taylor, P., Newsome, K. & Rainnie, A. (2013). Putting labour in its place: global value chains and labour process analysis. *Competition and Change, 17*(1), 1-5.

Verbrugge, B. (2014). Capital interests: A historical analysis of the transformation of small-scale gold mining in Compostela Valley province, Southern Philippines. *The Extractive Industries and Society*, 1(1), 86-95.

Verbrugge, B. & Besmanos, B. (2016). Formalizing Artisanal and Small-Scale Mining: Whither the Workforce? *Resources Policy*, 47, 134-41.

Verbrugge, B. & Geenen, S. (2020). *Global gold production touching ground. Expansion, informalization, and technological innovation*. Basingstoke: Palgrave.

Verbrugge, B., Lanzano, C. & Libassi, M. (2021). The cyanide revolution: efficiency gains and exclusion in artisanal and small-scale gold mining. *Geoforum*, 126, 267-276.

Vogel, C.; Musamba, J. & Radley, B. (2018). A miner's canary in eastern Congo: Formalisation of artisanal 3T mining and precarious livelihoods in South Kivu. *The Extractive Industries and Society*, 5, 73-80.

Weng, L. & Margules, C. (2022). Challenges with formalizing artisanal and small-scale mining in Cameroon: Understanding the role of Chinese actors. *The Extractive Industries and Society* 9, 101046.